High Power Laser Diode Arrays for 2-micron Solid State Coherent Lidars Applications

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I. INTRODUCTION

Laser diode arrays are critical components of any diode-pumped solid state laser systems, constraining their performance and reliability. Laser diode arrays (LDAs) are used as the pump source for energizing the solid state lasing media to generate an intense coherent laser beam with a high spatial and spectral quality. The solid state laser design and the characteristics of its lasing materials define the operating wavelength, pulse duration, and power of the laser diodes. The pump requirements for high pulse energy 2-micron solid state lasers are substantially different from those of more widely used 1-micron lasers and in many aspects more challenging [1]. Furthermore, the reliability and lifetime demanded by many coherent lidar applications, such as global wind profiling from space and long-range clear air turbulence detection from aircraft, are beyond the capability of currently available LDAs. In addition to the need for more reliable LDAs with longer lifetime, further improvement in the operational parameters of high power quasi-cw LDAs, such as electrical efficiency, brightness, and duty cycle, are also necessary for developing cost-effective 2-micron coherent lidar systems for applications that impose stringent size, heat dissipation, and power constraints. Global wind sounding from space is one of such applications, which is the main driver for this work as part of NASA's Laser Risk Reduction Program.

This paper discusses the current state of the 792 nm LDA technology and the technology areas being pursued toward improving their performance. The design and development of a unique characterization facility for addressing the specific issues associated with the LDAs for pumping 2-micron coherent lidar transmitters and identifying areas of technological improvement will be described. Finally, the results of measurements to date on various standard laser diode packages, as well as custom-designed packages with potentially longer lifetime, will be reported.

II. LDA TECHNOLOGY ADVANCEMENT APPROACH

Recent advances in the development of high peak power quasi-CW LDAs in conductively-cooled packages will likely ease engineering problems resulting from physical and environmental constraints of solid state lidar instruments. However, despite these advances, the LDAs meeting the requirements of space-based and airborne coherent lidars still suffer from lifetime and reliability issues. Moderate to high pulse energy 2-micron solid state lasers require high power quasi-CW LDAs with minimum pulse durations of one millisecond at a wavelength of 792 nm. Yet it is this relatively long pulse duration that is one of the main causes of limited lifetime for these arrays. Such relatively long pulse duration causes the laser diode active regions to experience high temperatures and drastic thermal cycling. Thermal cycling of the active regions is considered the primary reason for rapid rate of reduction of the LDA's power, and the excessive temperature rise is the leading suspect of premature failure [2]. The extreme temperature rise during the pulse can create considerable stress within the individual bars due to localized heating and various thermal mismatches between the bars, the substrate, and the bonding materials leading to premature failure. The thermally-induced rapid degradation can be improved to some extent by careful design of the laser head ensuring efficient extraction of heat from the laser diode bars and by operating the diodes at a power level considerably less than their maximum rating. In order to better address the lifetime and reliability issues and to improve the efficiency of these long-pulsewidth laser diode pump arrays, different laser diode packages are being investigated leading to the design and development of new packages with better thermal characteristics. Table 1 below summarizes the current state of 792 nm LDA technology and the goals defined based on the requirements of moderate to high power coherent lidar applications. As can be seen from Table 1, further technology advancement and better understanding of 792 nm LDA properties are needed for the development of 2-micron lidar instruments requiring autonomous operation over an extended period. At the present time, there is no reliable data that can predict the long term operation of 792 nm LDAs.

Table 1. Requirements of high power qausi-CW Laser diode arrays for pumping 2-micron solid state lidar transmitters.

Parameter	Goal	Current State
Central Wavelength (nm)	792 +/- 1	792 +/- 3
Spectral Width (nm FWHM)	3	5
Peak Power Per Bar (W)	150	100
Pulse Width (msec)	1.5	1.0
Duty Cycle	3%	1%
Number of Bars	10	6
Bar Spacing (mm)	0.4	0.4
Electrical to Optical Efficiency	55%	45%
Wavelength Drift (nm/Bshots)	+/- 1	Unknown
Package	Conductively Cooled	Conductively Cooled
Lifetime (number of shots)	3×10^9	$<< 3 \times 10^9$

III. Laser Diode Pump Array Characterization

A Laser Diode Characterization Facility (LDCF) has been developed for evaluating the performance, reliability, and lifetime of various laser diode arrays under different operational conditions. The LDCF consists of two measurement stations: a Laser Diode Characterization Station and a Lifetime Test Station. The Characterization Station provides the basic characteristic parameters such as power, wavelength, linewidth, and efficiency. This setup is also capable of providing some specialized measurements that includes thermal profiling of laser diode facet and package, near and far field beam profiling, and high-resolution spectral measurements. The Lifetime Test Station, as illustrated in Fig. 1, is capable of simultaneous measurement of 8 LDAs using a common set of instruments for accurate comparative analysis and evaluation. The Lifetime Test Station is fully automated using a single computer to set operational and environmental parameters, acquire and archive data, flag anomalous data, and generating a number of warning and status alert messages when necessary.

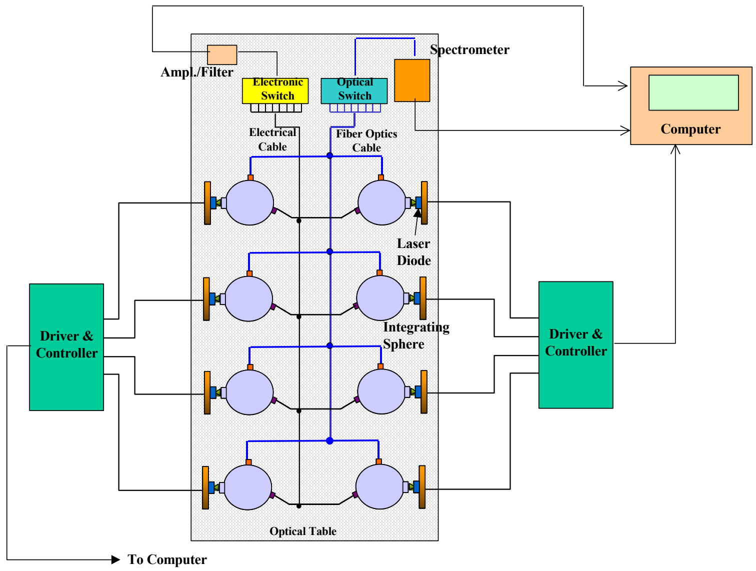

Figure 1. Laser diode pump array lifetime test setup.

An example of laser diode measurement is shown in Fig. 2 where the spectral characteristics of a conductively-cooled 6-bar array at 15 °C heatsink temperature is shown. The absorption spectrum of Ho,Tm;YLF laser material for s polarization is shown for reference. Fine tuning of the laser diode wavelength for maximum absorption in laser gain media is a critical criterion that is usually done by adjusting the laser diode heatsink temperature. Noteworthy is the wavelength shift and increase in spectral width with increased operating current which are also due to the laser diode junction temperature rise. Measuring the wavelength shift by varying the operating current or the pulse width is a common technique to indirectly determine the laser diode junction temperature and can be used for quantifying the thermal properties of different packages.

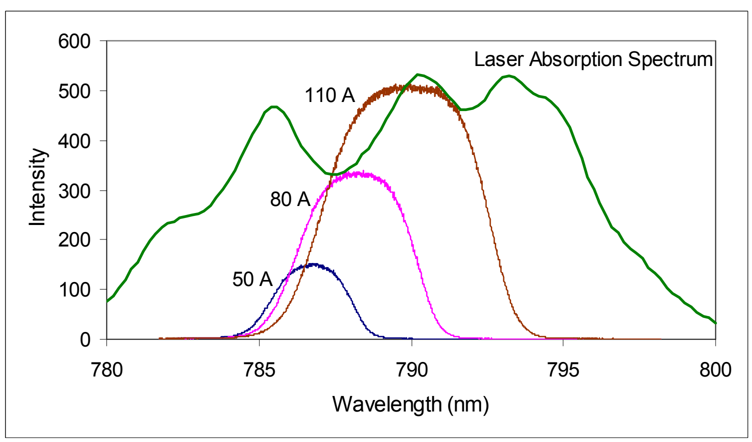

Figure 2. Spectral measurements of a 600W laser diode array.

As part of the effort to improve the lifetime and efficiency of laser diode pump arrays, a custom-designed package housing six 100W bars was fabricated by Cutting Edge Optronics, Inc. This experimental LDA uses a diamond substrate and heatsink, as opposed to conventional BeO substrate and copper heatsink, for improved heat removal from the active regions of the bars. The heat rejection efficiency of this package was determined by running the array at a constant current and repetition rate of 80A and 10 Hz respectively, while measuring its output wavelength and electrical efficiency at different pulsewidths. Fig. 3 is an example of the measurement results showing the laser diode temperature rise as a function of dissipated heat in the package for the diamond package and a similar package with BeO substrate and copper heatsink. The slope of the temperature vs. heat curve provides a figure of merit, referred to as thermal resistance, for each package's heat rejection efficiency. The measurements of Fig. 3 indicate a reduction of about 17% in thermal resistance of the diamond package. This is significant as it can translate to substantial increase in laser lifetime. One might interpret 17% reduction in thermal resistance of diamond package as being equivalent to operating the Cu/BeO package at 17% lower power to achieve the same lifetime. Future plan includes simultaneous lifetime testing of the diamond package devices and the standard (BeO) array packages available commercially.

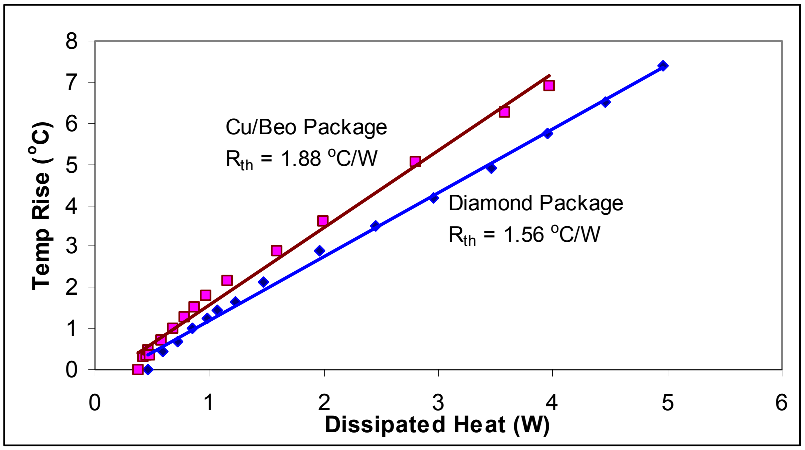

Figure 3. Thermal characteristics of 600 W laser diode arrays in diamond and BeO/Cu packages

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